III. *Experimental Researches in Electricity.—Twenty-first Series.*

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§ 27. *On new magnetic actions, and on the magnetic condition of all matter—continued.* ¶ v. *Action of magnets on the magnetic metals and their compounds.* ¶ vi. *Action of magnets on air and gases.* ¶ vii. *General considerations.*

¶ v. *Action of magnets on the magnetic metals and their compounds.*

2343. THE magnetic characters of iron, nickel and cobalt, are well known; and also the fact that at certain temperatures they lose their usual property and become, to ordinary test and observation, non-magnetic; then entering into the list of diamagnetic bodies and acting in like manner with them. Closer investigation, however, has shown me that they are still very different to other bodies, and that though inactive when hot, on common magnets or to common tests, they are not so absolutely, but retain a certain amount of magnetic power whatever their temperature; and also that this power is the same in character with that which they ordinarily possess.

2344. A piece of iron wire, about one inch long and 0·05 of an inch in diameter, being thoroughly cleaned, was suspended at the middle by a fine platinum wire connected with the suspending thread (2249.) so as to swing between the poles of the electro-magnet. The heat of a spirit-lamp was applied to it, and it soon acquired a temperature which rendered it quite insensible to the presence of a good ordinary magnet, however closely it was approached to the heated iron. The temperature of the iron was then raised considerably higher by adjustment of the flame, and the electro-magnet thrown into action. Immediately the hot iron became magnetic and pointed between the poles. The power was feeble, and in this respect the state of the iron was in striking contrast with that which it had when cold; but in character the force was precisely the same.

2345. The iron was then allowed to fall in temperature slowly so that its assumption of the higher magnetic condition might be observed. The intensity of the force did not appear to increase until the temperature arrived near a certain point, and

then as the heat continued to diminish, the iron rapidly, but not instantaneously, acquired its high magnetic power; at which time it could not be kept from the magnet, but flew to it, bending the suspending wire and trembling as it were with magnetic energy as it adhered by one end to the core.

2346. A small bar of nickel was submitted to an experimental examination in the same manner. This metal, as I have shown*, loses its magnetism as respects ordinary tests at a heat below that of boiling oil, and hence it is very well fitted to show whether the magnetic metals can have their power entirely removed by heat or not; and also, whether the disappearance of the whole or greater portion of their power is sudden or gradual. The smallness of the mass to be experimented on assisted much in the determination of the latter point. Upon being heated the nickel soon became indifferent to ordinary magnets; but however high the temperature, still it pointed to and was attracted by the electro-magnet. The power was very feeble, but certain. It was scarcely enough to sustain the weight of the nickel by the magnetic action alone; but was abundantly evident when the metal was supported as described (2344.).

2347. On carefully lowering the temperature of the nickel, it was again found that the transition from one degree of magnetic force to the other was progressive, and not instantaneous. With iron it is difficult to preserve all the parts, either in heating or cooling, so nearly at the same temperature as to be sure that it is not the union of hotter and colder portions which gives the appearance of an intermediate degree of magnetism; but with nickel that is not so difficult, for the progression is more gradual, so that when in cooling the power began to increase, the cooling might be continued some time before the full degree of power came on; at any time in that period the temperature might be slightly raised, and though the power would then diminish a little, it could yet be retained at a degree stronger than the weakest. In fact it was easy to *keep* the nickel at many of the intermediate degrees of power, and thus to remove all doubt of the progressive assumption of the full degree of force.

2348. I have expressed an opinion, founded on the different temperatures at which the magnetic metals appeared to lose their peculiar power†, that all the metals would probably have the same character of magnetism if their temperature could be lowered sufficiently. The facts just described appear to me entirely against such an opinion. The metals which are magnetic retain a portion of their power after the great change has been effected, or in what might be called their diamagnetic state; but the other metals, such as bismuth, tin, &c., present no trace of this power, and therefore are not in the condition of the heated iron, nickel, or cobalt; for in fact whilst these point axially and are attracted, the others point equatorially and are repelled. I therefore hope to be allowed to withdraw the view I then put forth.

2349. I next proceeded to examine the peroxides of iron, and in accordance with

* Philosophical Magazine, 1836, vol. viii. p. 179. † Ibid. 177; ibid. 1839, vol. xiv. p. 161.

the observations of M. Becquerel* and others, found them all, both natural and artificial, possessed of magnetic power at common temperatures. I heated them in tubes but found them still magnetic, suffering *no* diminution of the force by such temperature as I could apply to them.

2350. Different specimens of the oxide of nickel were found to present the same phenomena. They were magnetic both when hot and cold; and that heat should cause no change in this respect is the more striking, because the hot oxide had a temperature given to it far higher than that necessary to produce the great magnetic change in the metal itself (2346.).

2351. The oxide of cobalt also was magnetic, and equally magnetic whether hot or cold. Glass coloured blue by cobalt is magnetic in consequence of the presence of the oxide of that metal, and is so whether hot or cold. In all these cases the degree of power retained was very small compared to that of the pure metal.

2352. Proceeding to the *salts* of iron, I found them magnetic. Clean crystals of the proto-sulphate of iron were attracted and pointed axially very well; so also did the dry salt. As I proceeded I found that every salt and compound containing iron in the basic part was magnetic. To enumerate the different substances subjected to trial would be tedious, the following are selected as illustrations of the variety in kind:—

Protochloride.	Protophosphate.
Perchloride.	Perphosphate.
Iodide.	Nitrate.
Protosulphate.	Carbonate.
Persulphate.	Prussian blue.

2353. Amongst native compounds—

Bog iron ore.	Yellow sulphuret of iron.
Hæmatite.	Arsenical pyrites.
Chromate of iron.	Copper pyrites, and many others were magnetic.

2354. Green bottle-glass is comparatively very magnetic from the iron it contains, and cannot be used as tubes to hold other substances. Crown-glass is magnetic from the same cause. Flint-glass is not magnetic, but points equatorially.

2355. Crystals of the yellow ferro-prussiate of potassa were not magnetic, but were repelled and set equatorially; and such was the case also with red ferro-prussiate.

2356. According to my hopes, even the solutions of the ferruginous salts, whether in water or alcohol, were magnetic. A tube filled with a clear solution of proto- or persulphate of iron, or proto- or perchloride, or tincture of muriate of iron, was attracted by the poles, and pointed very well between them in the axial direction.

2357. These solutions supply a very important means of advancing magnetical investigation, for they present us with the power of making a magnet, which is at the same time liquid, transparent, and within certain limits, adjustible to any degree

* Annales de Chimie, 1827, vol. xxxvi. p. 337. Comptes Rendus, 1845, vol. xx. p. 1708.

of strength. Hence the power of examining a magnet optically. Hence also, the capability of placing magnetic portions of matter one within another, and so observing dynamic and other phenomena within magnetic media. In fact, not only may these substances be placed as magnets in the magnetic field, but the field generally may be filled with them, and then other bodies and other magnets examined as to their joint or separate actions in it (2361., &c.).

2358. In reference to the salts of *nickel* and *cobalt,* pure crystals of the sulphate of nickel were found to be well magnetic, and also pure crystals of sulphate of cobalt. Solutions of the sulphate of nickel, the chloride of nickel, and the chloride of cobalt, were also magnetic. That I might be perfectly safe in these conclusions I applied to Mr. Askin of Birmingham, whose power of separating nickel and cobalt from each other and other metals is well known, as also the scale upon which he carries on these operations, and he favoured me with a solution of chloride of nickel, and another of chloride of cobalt perfectly pure, both of which proved to be well magnetic between the poles of my magnet.

2359. Heat applied to any of these magnetic solutions did not diminish or affect their power.

2360. These results with the salts of the magnetic metals conjoin with those before quoted, as tending to show that the non-magnetic metals could not by any change of temperature be rendered magnetic (2398.), but as a class are distinct from iron, nickel, and cobalt; for none of the compounds of the non-magnetic metals show, as yet, any indication of ordinary magnetic force, whereas in respect of these three substances all their compounds possess it.

2361. In illustration of the power which the iron and other similar solutions give in the investigation of magnetic phenomena (2357.), as well as in reference to the general conclusions to be drawn from all the facts described in this paper, I will proceed to describe certain anticipated results which were obtained by the employment of these solutions in the magnetic field.

2362. A clear solution of the proto-sulphate of iron was prepared, in which one ounce of the liquid contained seventy-four grains of the hydrated crystals; a second solution was prepared containing one volume of the former and three volumes of water; a third solution was made of one volume of the stronger solution and fifteen volumes of water. These solutions I will distinguish as Nos. 1, 2, and 3; the proportions of crystals of sulphate of iron in them were respectively as 16, 4, and 1 per cent. nearly. These numbers may, therefore, be taken as representing (generally only (2423.)) the strength of the magnetic part of the liquids.

2363. Tubes like that before described (2279.) were prepared and filled respectively with these solutions and then hermetically sealed, as little air as possible being left in them. Glasses of the solutions were also prepared, large enough to allow the tubes to move freely in them, and yet of such size and shape as would permit of their being placed between the magnetic poles. In this manner the action of the

magnetic forces upon the matter in the tubes could be examined and observed, both when the tubes were in diamagnetic media, as air, water, alcohol, &c., and also in magnetic media, either stronger or weaker in magnetic force than the substances in the tubes.

2364. When these tubes were suspended in air between the poles, they all pointed axially or magnetically, as was to be expected; and with forces apparently proportionate to the strengths of the solutions. When they were immersed in alcohol or water, they also pointed in the same direction; the strongest solution very well, and also the second, but the weakest solution was feeble in its action though very distinct in its character (2422.).

2365. When the tubes, immersed in the different ferruginous solutions, were acted upon, the results were very interesting. The tube No. 1 (the strongest magnetically), when in solution No. 1, had no tendency, under the influence of the magnetic power, to any particular position, but remained wherever it was placed. Being placed in solution No. 2, it pointed well axially, and in solution No. 3 it took the same direction, but with still more power.

2366. The tube No. 2, when in the solution No. 1, pointed equatorially, *i. e.* as heavy glass, bismuth, or a diamagnetic body generally, in air. In solution No. 2 it was indifferent, not pointing either way; and in solution No. 3 it pointed axially, or as a magnetic body. The tube No. 3 containing the weakest solution, pointed equatorially in solutions No. 1 and 2, and not at all in solution No. 3.

2367. Several other ferruginous solutions varying in strength were prepared, and, as a general and constant result, it was found that any tube pointed axially if the solution in it was stronger than the surrounding solution, and equatorially if the tube solution was the weaker of the two.

2368. The tubes were now suspended vertically, so that being in the different solutions they could be brought near to one of the magnetic poles, and employed in place of the indicating cube or sphere of bismuth, or heavy glass (2266.). The constant result was, that when the tube contained a stronger solution than that which surrounded it, it was attracted to the pole, but when its solution was the weaker of the two it was repelled. The latter phenomena were as to appearance in every respect the same as those presented in the repulsion of heavy glass, bismuth, or any other diamagnetic body in air.

2369. Having described these phenomena, I will defer their further consideration until I arrive at the last division of this paper, and proceed to certain results more especially belonging to the present part of these Researches.

2370. As the magnetic metals, iron, nickel and cobalt, present in their compounds substances also distinguished by the possession of magnetic properties (2360.), so it appeared very probable that other metals, of whose magnetic character doubts were entertained, because of the possible presence of iron in the specimens experimented with, might in this way have their magnetic character tested; for it seemed likely, from analogy, that every metal well magnetic *per se,* would be magnetic in its com-

pounds; and, judging from the character of the great class of diamagnetic bodies (2275.), that no magnetic compounds would be obtained of a metal not magnetic of itself. Accordingly I proceeded to apply this kind of test to the combinations of many of the metals, and obtained the following results :—

2371. *Titanium.*—WOLLASTON has described the magnetic effects of crystals of titanium, expressing at the same time a belief that they are due to iron*. I took a specimen of the oxide of titanium, which I believe to be perfectly free from iron, and inclosing it in a tube (2279.), subjected it to the action of the electro-magnet (2246. 2247.). It proved to be freely magnetic. Another specimen obtained from Mr. JOHNSON, and believed by him to be perfectly free from iron, was also magnetic. Hence I conclude that titanium is truly a magnetic metal.

2372. *Manganese.*—BERTHIER, as far as I am aware, first announced that this metal was magnetic at very low temperatures†. On submitting specimens of the various oxides, which were considered as pure, to the magnetic force, they were all found to be magnetic, especially the protoxide. So were the following compounds of manganese in the pure, dry, or crystallized state :—chloride, sulphate, ammonio-sulphate, phosphate, carbonate, borate ; and also the chloride, nitrate, sulphate, and ammonio-sulphate when in solution. A specimen of the ammonio-sulphate was rendered alkaline by the addition of a little carbonate of ammonia boiled and then carefully crystallized thrice ; after that the crystals and solution of the purified salt were perfectly and well magnetic. I have no doubt, therefore, that manganese is a magnetic metal, as BERTHIER said. If any opinion may be drawn concerning the magnetic force of the metal from the degree of magnetism of the compounds, I should expect that manganese possesses considerable power of this kind when at a sufficiently low temperature‡.

2373. *Cerium.*—I am not aware that cerium has as yet been classed with the magnetic metals. Having made experiments with the hydrated protoxide, the carbonate, and the chloride of this metal, and also with the double sulphate of the oxide and potassa prepared with great care, I found them all magnetic; and those that are soluble are magnetic in the state of solution. Hence, as the compounds are undoubtedly magnetic, there is every reason to believe that cerium also is a magnetic metal (2370.).

2374. *Chromium.*—The magnetic phenomena of chromium compounds are very interesting. Portions of the chromate and the bichromate of potassa were purified by three careful crystallizations each; part of the bichromate was heated in a platinum crucible, until the second equivalent of chromic acid was converted into the crystallized oxide, and this being washed out and dried was found to be well magnetic. So were all the other specimens of oxide of chromium which were examined.

A specimen of WARRINGTON's chromic acid was found to be very feebly magnetic.

* Philosophical Transactions, 1823, p. 400.

† Traité des Essais par la Voie Sêche, tome i. p. 532. Philosophical Magazine, 1845, vol. xxvii. p. 2.

‡ Philosophical Magazine, 1845, vol. xxvii. p. 2.

2375. Chromate of lead, when subjected to the magnet, pointed equatorially and was repelled. Such was the case also with crystals of the chromate of potassa. Crystals of the bichromate, however, did not act thus; for if in any way affected they were in the least degree magnetic, showing the influence of the increased proportion of chromic acid. Solutions of either salt pointed well equatorially and were repelled; thus showing the diamagnetic influence of the water present (2422.).

2376. As just stated, a solution of the bichromate contained in a tube, pointed equatorially and was repelled; but if the same solution had a little alcohol added to it, and also some pure muriatic or sulphuric acid, and were then heated for a few minutes to reduce the chromic acid to the state of oxide or chloride, then, on being returned to the tube and subjected to the magnet, it was found strongly magnetic.

2377. I think it has before been said that chromium is a magnetic metal; as these results have been obtained with its pure compounds, there is no longer any doubt on my mind that such is the case.

2378. *Lead.*—The compounds of lead point equatorially and are repelled. The substances tried were the chloride, iodide, sulphuret, nitrate, sulphate, phosphate, carbonate, protoxide fused, and the acetate. A portion of very carefully crystallized nitrate being dissolved was precipitated by pure zinc, and the lead obtained washed with dilute nitric acid, to remove subsalts. Such lead was free from magnetism, and therefore the metal ranks in the diamagnetic class, both directly and by its compounds. Lead usually appears to be magnetic, and it is not very easy to obtain the metal in the pure diamagnetic state.

2379. *Platinum.*—I have, as yet, found no wrought specimens of this metal free from magnetism, not even those prepared by Dr. Wollaston himself, and left with the Royal Society. Specimens of the purest platinum obtained from Mr. Johnson were also found to be slightly magnetic.

2380. Clean platinum foil and cuttings were dissolved in pure nitro-muriatic acid, and the solution evaporated to dryness. Both the solution and the dry chloride pointed equatorially and were repelled by the magnet. A part of the chloride being dissolved and rendered acid, was precipitated by an acid solution of muriate of ammonia, and the ammonio-chloride of platinum washed and dried: it also, at the magnet, pointed equatorially and was repelled. A portion of this ammonio-chloride, decomposed in a flint-glass tube by heat, gave spongy platinum, which being pressed together into a cake, pointed *axially* and was attracted at the side of the magnetic pole, being magnetic.

2381. At present I believe that platinum is as a metal magnetic, though very slightly so; and that in the compounds, the change of state and the presence of other substances having the diamagnetic character, are sufficient to cover this property and make the whole compound diamagnetic (2422.).

2382. *Palladium.*—All the palladium in the possession of the Royal Society, prepared by Dr. Wollaston, amounting to ten ingots and rolled plates, is magnetic.

Specimens of the metal from Mr. JOHNSON, considered as pure, were also slightly magnetic. The chloride, the ammonio-bichloride, and the cyanuret of palladium, pointed equatorially and were repelled by the magnet. The same cyanuret, reduced by heat either in open platinum vessels or in close glass tubes, gave palladium possessing a feeble degree of magnetic property. Some of WOLLASTON'S palladium was dissolved in pure nitromuriatic acid, and the solution slowly acted upon by pure zinc, free from iron, and not magnetic. Five successive portions of the precipitated metal were collected, and *all* were *magnetic.* Ammonio-bichloride of palladium was prepared from the same solution by pure acid muriate of ammonia, and digested in nitromuriatic acid. The salt itself was repelled, being diamagnetic; but when reduced by heat in glass tubes, or in Berlin capsules, the palladium obtained was magnetic. From the result of all the experiments, I believe the metal to be feebly but truly magnetic.

2383. *Arsenic.*—This metal required very particular examination, and even when carefully sublimed twice or thrice in succession, presented appearances which sometimes made me class it with the magnetic, and at other times with the diamagnetic bodies. On the whole, I incline to believe that it belongs to the latter series of substances, being only in a very small degree removed from the zero or medium point. Pure white arsenic points freely in an equatorial direction, and is repelled by a magnetic pole.

2384. In reference to the pointing of short bars between magnetic poles exposing large flat faces, I ought to observe, that such bars will sometimes point axially and seem to be magnetic when they do not belong to that class, and are repelled by a single pole. The cause of this effect has been already given (2298. 2299.), and is obviated by the use of poles having wedge-shaped or conical terminations.

2385. *Osmium.*—Osmic acid from Mr. JOHNSON, in fine transparent crystals, was clearly diamagnetic, being repelled. Specimens of the metal and of the protoxide were both slightly magnetic. The protoxide had been obtained by the action of alcohol on a solution of osmic acid which had twice been distilled with water, and the metal was believed to be perfectly free from other substances. Probably, therefore, osmium belongs to the magnetic class.

2386. *Iridium.*—Mr. JOHNSON supplied me with several preparations of iridium. The oxide, chloride, and ammonio-chloride were magnetic; and so was a sample of the metal. One specimen of the metal, which seemed to be very pure, was scarcely at all magnetic; and on the whole, I incline to believe that iridium does not stand in the magnetic class.

2387. *Rhodium.*—A well-fused specimen of this metal, prepared by Dr. WOLLASTON, was magnetic; but crystals of the chloride and the sodio-chloride of rhodium prepared by the same philosopher, and others also from Mr. JOHNSON, were not magnetic, but pointed well equatorially. I conclude, therefore, that the metal is probably not magnetic, or if magnetic, is but little removed from the zero point.

2388. *Uranium.*—Peroxide of this metal was obtained not magnetic; protoxide very slightly magnetic: I have set the metal for the present in the diamagnetic class.

2389. *Tungsten.*—The oxide of this metal, and also the acid, were submitted to examination, and found to point well equatorially. The acid was distinctly repelled by a single magnetic pole; the oxide appeared nearly neutral. Hence I have, for the present, considered tungsten as a diamagnetic metal.

2390. *Silver* is not magnetic (2291.), nor its compounds.

2391. *Antimony* is not magnetic (2291.), nor its compounds.

2392. *Bismuth* is not magnetic (2291.), nor its compounds.

Having tried many of the compounds of each of these three metals, I thought it well to record the accordance existing between them and their metallic bases (2370.).

2393. *Sodium.*—A fine large globule, equal to half a cubic inch in size, was well repelled, and is therefore diamagnetic.

2394. *Magnesium.*—None of the compounds or salts of this base are magnetic.

2395.	Calcium.	Sodium.
	Strontium.	Potassium.
	Barium.	Ammonia.

None of the compounds or salts of these substances are magnetic.

2396. From the characters, therefore, of the compounds, as well as from direct evidence in respect of some of the metals, it would appear that, besides iron, nickel, and cobalt, the following are also magnetic; namely, titanium, manganese, cerium, chromium, palladium, platinum. It is, however, very probable that there may be metals possessing distinct magnetic power, yet in so slight a degree as, like platinum and palladium, not to exhibit in their compounds any sensible trace of it. Such may be the case with tungsten, uranium, rhodium, &c.

2397. I have heated several of the diamagnetic metals, even up to their fusing-points, but have not been able to observe any change, either in the character or degree of their magnetic relations.

2398. Perhaps the cooling of some of the metals, whose compounds, like those of iron, nickel and cobalt, are magnetic, might develope in them a much higher degree of force than any which they have as yet been known to possess. Manganese, chromium, cerium, titanium, are metals of much interest in this point of view. Osmium, iridium, rhodium and uranium, ought to be subjected with them to the same trial.

2399. The following is an attempt to arrange some of the metals in order, as respects their relation to magnetic force. The 0° or medium point is supposed to be the condition of a metal or substance indifferent to the magnetic force as respects attraction or repulsion in air or space. The further substances are placed from this point, the more distinctive are they as regards their attraction or repulsion by the magnet. Nevertheless this order may, very probably, be found inaccurate by more careful observation.

Magnetic.	Diamagnetic.
	Bismuth.
	Antimony.
	Zinc.
	Tin.
	Cadmium.
	Sodium.
Iron.	Mercury.
Nickel.	Lead.
Cobalt.	Silver.
Manganese.	Copper.
Chromium.	Gold.
Cerium.	Arsenic.
Titanium.	Uranium.
Palladium.	Rhodium.
Platinum.	Iridium.
Osmium.	Tungsten.

0°.

¶ vi. *Action of magnets on air and gases.*

2400. It was impossible to advance in an experimental investigation of the kind now described, without having the mind impressed with various theoretical views of the mode of action of the bodies producing the phenomena. In the passing consideration of these views, the apparently middle condition which *air* held between magnetic and diamagnetic substances was of the utmost interest, and led to many experiments upon its probable influence, which I will now proceed briefly to describe.

2401. A thin flint-glass tube, in which common air was hermetically enclosed, was placed between the magnetic poles (2249.) surrounded by air, and the effect of the magnetic force observed upon it. There was a very feeble tendency of the tube to an equatorial position, due to the substance of the tube in which the air was enclosed.

2402. The air was then withdrawn from around the tube more or less, and at last up to the highest amount which a good air-pump would effect; but whatever the degree of rarefaction, the tube of air still seemed to be affected exactly in the same manner as if surrounded by air of its own density.

2403. I then surrounded the air-tube with hydrogen and carbonic acid in succession; but in both these, and in each of them at different degrees of rarefaction, the tube of air remained as indifferent as before.

2404. Hence there appears to be no sensible distinction between dense or rare air; or, as far as these experiments go, between one gas or vapour and another.

2405. As it did not seem at all unlikely that the equatorial and axial set of bodies.

or their repulsions and attractions, might depend upon converse actions of the media by which they were surrounded (2361.), so I proceeded to examine what would occur with diamagnetic substances, when the air or gas which surrounded them was changed in its density or nature, or what would happen to air itself when surrounded by these substances.

2406. The air-tube (2401.) was suspended horizontally in water (being retained below the surface by a cube of bismuth attached to it, just beneath the point of suspension, which therefore could have no power of giving it direction); it was then subjected to the magnetic forces, and immediately pointed well in an axial direction, or as a magnet would have done. Being brought near to one pole it moved, on the supervention of the magnetic force, appearing as if *attracted* after the manner of a magnetic body; and this continued as long as the magnetic force was sustained in action.

2407. The air-tube was in like manner subjected to the action of the magnetic force, when surrounded by alcohol, and also by oil of turpentine, with precisely the same results as in water. In all these cases the action of air in the fluids was precisely the same as the action of a magnetic body in air. The air-tube was subjected to the action of the magnet even when under the surface of mercury, and here also it pointed axially.

2408. In order to extend the experimental relations of air and gases, I proceeded to place substances of the diamagnetic class in them. Thus, the bar of heavy glass (2253.) was suspended in a jar of air, and then the air about it more or less rarefied, but, as before, in the case of the air-tube (2402.), alterations of this kind produced no effect. Whether the bar were in air at the ordinary pressure, or as rare as the pump could render it, it still pointed equatorially, and apparently always with the same degree of force.

2409. The bar of bismuth (2296.) was suspended in the jar, and the same alteration in the density of the air made as before; but this caused no difference in the action of the bismuth, either in kind or degree. Carbonic acid and hydrogen gases were then introduced in succession into the jar, and these also were employed in different degrees of rarefaction, but the results were the same; no change took place in the action on the bismuth.

2410. A bismuth cube was suspended in air and gases at ordinary pressure, and also rarefied as much as could be, and under these circumstances it was brought near the magnetic pole and its repulsion observed; its action was in all these cases precisely the same as in the atmosphere.

2411. The perpendicular copper bar (2323.) was suspended near the magnetic pole *in vacuo*, but its set, sluggish movements and revulsion, were just the same as before in air (2324.).

2412. The following preparations in tubes (2401.), namely, a vacuum, air, hydrogen, carbonic acid gas, sulphurous acid gas, and vapour of ether, were surrounded

by water, and then subjected to the magnetic force; they all pointed axially, and, as far as I could perceive, with equal force. Being placed in alcohol the same effect occurred.

2413. The same preparations being surrounded by air, or by carbonic acid gas, all set equatorially.

2414. The axial position of the tubes in the liquid (2412.) depends, doubtless, upon the relation of the contents of the tube to the surrounding medium; for as far as the matter of the tube is concerned, it alone would have tended to give the equatorial position. In the following succeeding experiments (2413.), where the tubes of gases were in surrounding gases, the equatorial position is due to this effect of the glass of the tube; and that it should produce its constant feeble effect, undisturbed by all the variations of the gases and vapours, is a proof how like and how indifferent these are one to the other.

2415. I suspended a tube of liquid sulphurous acid in gaseous sulphurous acid; when under the magnetic influence, the liquid pointed well equatorially. I surrounded liquid nitrous acid by gaseous nitrous acid; the liquid pointed well equatorially. I placed liquid ether in the vapour of ether; the former pointed equatorially. Upon suspending the tube of vapour of ether in liquid ether, the vapour pointed axially.

2416. In every kind of trial, therefore, and in every form of experiment, the gases and vapours still occupy a medium position between the magnetic and the diamagnetic classes. Further, whatever the chemical or other properties of the substances, however different in their specific gravity, or however varied in their own degree of rarefaction, they all become alike in their magnetic relation, and apparently equivalent to a perfect vacuum. Bodies which are very marked as diamagnetic substances, immediately lose all traces of this character when they become vaporous (2415.). It would be exceedingly interesting to know whether a body from the magnetic class, as chloride of iron, would undergo the same change.

¶ vii. *General considerations.*

2417. Such are the facts which, in addition to those presented by the phenomena of light, establish a magnetic action or condition of matter new to our knowledge. Under this action, an elongated portion of such matter usually (2253. 2384.) places itself at right angles to the lines of magnetic force; this result may be resolved into the simpler one of repulsion of the matter by either magnetic pole. The set of the elongated portion, or the repulsion of the whole mass, continues as long as the magnetic force is sustained, and ceases with its cessation.

2418. By the exertion of this new condition of force, the body moved may pass either *along* the magnetic lines or *across* them; and it may move along or across them in either or any direction. So that two portions of matter, simultaneously subject to this power, may be made to approach each other as if they were mutually

attracted, or recede as if mutually repelled. All the phenomena resolve themselves into this, that a portion of such matter, when under magnetic action, tends to move from stronger to weaker places or points of force. When the substance is surrounded by lines of magnetic force of equal power on all sides, it does not tend to move, and is then in marked contradistinction with a linear current of electricity under the same circumstances.

2419. This condition and effect is new, not *only* as it respects the exertion of power by a magnet over bodies previously supposed to be indifferent to its influence, but is *new* as a magnetic action, presenting us with a second mode in which the magnetic power can exert its influence. These two modes are in the same general antithetical relation to each other as positive and negative in electricity, or as northness and southness in polarity, or as the lines of electric and magnetic force in magneto-electricity; and the diamagnetic phenomena are the more important, because they extend largely, and in a new direction, that character of duality which the magnetic force already, in a certain degree, was known to possess.

2420. All matter appears to be subject to the magnetic force as universally as it is to the gravitating, the electric and the chemical or cohesive forces; for that which is not affected by it in the manner of ordinary magnetic action, is affected in the manner I have now described; the matter possessing for the time the solid or fluid state. Hence substances appear to arrange themselves into two great divisions, the magnetic, and that which I have called the diamagnetic classes; and between these classes the contrast is so great and direct, though varying in degree, that where a substance from the one class will be attracted, a body from the other will be repelled; and where a bar of the one will assume a certain position, a bar of the other will acquire a position at right angles to it.

2421. As yet I have not found a single solid or fluid body, not being a mixture, that is perfectly neutral in relation to the two lists; *i. e.* that is neither attracted nor repelled in air. It would probably be important to the consideration of magnetic action, to know if there were any natural simple substance possessing this condition in the solid or fluid state. Of compound or mixed bodies there may be many; and as it may be important to the advancement of experimental investigation, I will describe the principles on which such a substance was prepared when required for use as a circumambient medium.

2422. It is manifest that the properties of magnetic and diamagnetic bodies are in opposition as respects their dynamic effects; and, therefore, that by a due mixture of bodies from each class, a substance having any intermediate degree of the property of either may be obtained. Protosulphate of iron belongs to the magnetic, and water to the diamagnetic class; and using these substances, I found it easy to make a solution which was neither attracted nor repelled, nor pointed when in air. Such a solution pointed axially when surrounded by water. If made somewhat weaker in respect of the iron, it would point axially in water but equatorially in air; and it

could be made to pass more and more into the magnetic or the diamagnetic class by the addition of more sulphate of iron or more water.

2423. Thus a *fluid* medium was obtained, which, practically, as far as I could perceive, had every magnetic character and effect of a gas, and even of a vacuum; and as we possess both magnetic and diamagnetic glass (2354.), it is evidently possible to prepare a *solid* substance possessing the same neutral magnetic character.

2424. The endeavour to form a general list of substances in the present imperfect state of our knowledge would be very premature: the one below is given therefore only for the purpose of conveying an idea of the singular association under which bodies come in relation to magnetic force, and for the purpose of general reference hereafter:—

Iron.
Nickel.
Cobalt.
Manganese.
Palladium.
Crown-glass.
Platinum.
Osmium.
0° Air and vacuum.
Arsenic.
Ether.
Alcohol.
Gold.
Water.
Mercury.
Flint-glass.
Tin.
Heavy glass.
Antimony.
Phosphorus.
Bismuth.

2425. It is very interesting to observe that metals are the substances which stand at the extremities of the list, being of all bodies those which are most powerfully opposed to each other in their magnetic condition. It is also a very remarkable circumstance that these differences and departures from the medium condition, are in the metals at the two extremes, iron and bismuth, associated with a small conducting power for electricity. At the same time the *contrast* between these metals, as to their fibrous and granular state, their malleable and brittle character, will press upon the mind whilst contemplating the possible condition of their molecules when subjected to magnetic force.

2426. In reference to the metals, as well as the diamagnetics not of that class (2286.), it is satisfactory to have such an answer to the opinion that all bodies are magnetic as iron, as does not consist in a mere negation of that which is affirmed, but in proofs that they are in a different and opposed state, and are able to counteract a very considerable degree of magnetic force (2448.).

2427. As already stated, the magnetic force is so strikingly distinct in its action upon bodies of the magnetic and the diamagnetic class, that when it causes the attraction of the one it produces the repulsion of the other; and this we cannot help referring, in some way, to an action upon the molecules or the mass of the substances acted upon, by which they are thrown into different conditions and affected accordingly. In that point of view it is very striking to compare the results with those which are presented to us by a polarized ray, especially as then a remarkable difference comes into view; for if transparent bodies be taken from the two classes, as for instance, heavy glass or water from the diamagnetic, and a piece of green glass or a solution of green vitriol from the magnetic class, then a given line of magnetic force will cause the repulsion of one and the attraction of the other; but this same line of force which thus affects the particles so differently, affects the polarized ray when passing through them precisely in the *same* manner in both cases; for the two bodies cause its rotation in the *same* direction (2160. 2199. 2224.).

2428. This consideration becomes even more important when we connect it with the diamagnetic and the optical properties of bodies which rotate a polarized ray. Thus the iron solution and a piece of quartz, having the power to rotate a ray, point by the influence of the *same* line of magnetic force, the one axially and the other equatorially; but the rotation which is impressed on a ray of light by these two bodies, as far as they are under the influence of the same magnetic force, is the *same* for both. Further, this rotation is quite independent of, and quite unlike that of the quartz in a most important point; for the quartz by itself can only rotate the ray in one direction, but under the influence of the magnetic force it can rotate it both to the right and left, according to the course of the ray (2231. 2232.). Or, if two pieces of quartz (or two tubes of oil of turpentine) be taken which can rotate the ray *different* ways, the further rotative force manifested by them when under the dominion of the magnetism is always the *same* way; and the direction of that way may be made either to the right or left in either crystal of quartz. All this time the *contrast* between the quartz as a diamagnetic, and the solution of iron as a magnetic body remains undisturbed. Certain considerations regarding the character of a ray, arising from these contrasts, press strongly on my mind, which, when I have had time to submit them to further experiment, I hope to present to the Society.

2429. Theoretically, an explanation of the movements of the diamagnetic bodies, and all the dynamic phenomena consequent upon the actions of magnets on them, might be offered in the supposition that magnetic induction caused in them a contrary state to that which it produced in magnetic matter; *i. e.* that if a particle of

each kind of matter were placed in the magnetic field both would become magnetic, and each would have its axis parallel to the resultant of magnetic force passing through it; but the particle of magnetic matter would have its north and south poles opposite, or facing towards the contrary poles of the inducing magnet, whereas with the diamagnetic particles the reverse would be the case; and hence would result approximation in the one substance, recession in the other.

2430. Upon AMPÈRE's theory, this view would be equivalent to the supposition, that as currents are induced in iron and magnetics parallel to those existing in the inducing magnet or battery wire; so in bismuth, heavy glass and diamagnetic bodies, the currents induced are in the contrary direction. This would make the currents in diamagnetics the same in direction as those which are induced in diamagnetic conductors at the *commencement* of the inducing current; and those in magnetic bodies the same as those produced at the *cessation* of the same inducing current. No difficulty would occur as respects non-conducting magnetic and diamagnetic substances, because the hypothetical currents are supposed to exist not in the mass, but round the particles of the matter.

2431. As far as experiment yet bears upon such a notion, we may observe, that the known inductive effects upon masses of magnetic and diamagnetic metals *are the same.* If a straight rod of iron be carried across magnetic lines of force, or if it, or a helix of iron rods or wire, be held near a magnet, as the power in it rises electric currents are induced, which move through the bars or helix in certain determinate directions (38. 114., &c.). If a bar or a helix of bismuth be employed under the same circumstances the currents are again induced, and precisely in the same direction as in the iron, so that here no difference occurs in the direction of the induced current, and not very much in its force, nothing like so much indeed as between the current induced in either of these metals and a metal taken from near the neutral point (2399.). Still there is this difference remaining between the conditions of the experiment and the hypothetical case; that in the former the induction is manifested by currents in the masses, whilst in the latter, *i. e.* in the special magnetic and diamagnetic effects, the currents, if they exist, are probably about the particles of the matter.

2432. The magnetic relation of aëriform bodies is exceedingly remarkable. That oxygen or nitrogen gas should stand in a position intermediate between the magnetic and diamagnetic classes; that it should occupy the place which *no* solid or liquid element can take; that it should show no change in its relations by rarefaction to any possible degree, or even when the space it occupies passes into a vacuum; that it should be the same magnetically with any other gas or vapour; that it should not take its place at one end but in the very middle of the great series of bodies; and that all gases or vapours should be alike, from the rarest state of hydrogen to the densest state of carbonic acid, sulphurous acid, or ether vapour, are points so striking,

as to persuade one at once that air must have a great and perhaps an active part to play in the physical and terrestrial arrangement of magnetic forces.

2433. At one time I looked to air and gases as the bodies which, allowing attenuation of their substance without addition, would permit of the observation of corresponding variations in their magnetic properties; but now all such power by rarefaction appears to be taken away; and though it is easy to prepare a liquid medium which shall act with other bodies as air does (2422.), still it is not truly in the same relation to them; neither does it allow of dilution, for to add water or any such substance is to add to the diamagnetic power of the liquid; and, if it were possible to convert it into vapour and so dilute it by heat, it would pass into the class of gases and be magnetically undistinguishable from the rest.

2434. It is also very remarkable to observe the apparent disappearance of magnetic condition and effect when bodies assume the vaporous or gaseous state, comparing it at the same time with the similar relation to light; for as yet no gas or vapour has been made to show any magnetic influence over the polarized ray, even by the use of powers far more than enough to manifest such action freely in liquid and solid bodies.

2435. Whether the negative results obtained by the use of gases and vapours depend upon the smaller quantity of matter in a given volume, or whether they are direct consequences of the altered physical condition of the substance, is a point of very great importance to the theory of magnetism. I have imagined, in elucidation of the subject, an experiment with one of M. CAGNIARD DE LA TOUR's ether tubes, but expect to find great difficulty in carrying it into execution, chiefly on account of the strength, and therefore the mass of the tube necessary to resist the expansion of the imprisoned heated ether.

2436. The remarkable condition of air and its relation to bodies taken from the magnetic and the diamagnetic classes, causes it to point equatorially in the former and axially in the latter. Or, if the experiment presents its results under the form of attraction and repulsion, the air moves as if repelled in a magnetic medium and attracted in a medium from the diamagnetic class. Hence it seems as if the air were magnetic when compared with diamagnetic bodies, and of the latter class when compared to magnetic bodies.

2437. This result I have considered as explained by the assumption that bismuth and its congeners are absolutely repelled by the magnetic poles, and would, if there were nothing else concerned in the phenomenon than the magnet and the bismuth, be equally repelled. So also with the iron and its similars, the attraction has been assumed as a direct result of the mutual action of them and the magnets; further, these actions have been admitted as sufficient to account for the pointing of the air both axially and equatorially, as also for its apparent attraction and repulsion; the effect in these cases being considered as due to the travelling of the air to those positions which the magnetic or diamagnetic bodies tended to leave.

2438. The effects with air are, however, in these results precisely the same as those which were obtained with the solutions of iron of various strength (2365.), where *all* the bodies belonged to the magnetic class, and where the effect was evidently due to the greater or smaller degree of magnetic power possessed by the solutions. A weak solution in a stronger pointed equatorially and was repelled like a diamagnetic, not because it did not tend by attraction to an axial position, but because it tended to that position with less force than the matter around it; so the question will enter the mind, whether the diamagnetics, when in air, are repelled and tend to the equatorial position for any other reason, than that the air is more magnetic than they are, and tends to occupy the axial space. It is easy to perceive that if all bodies were magnetic in different degrees, forming one great series from end to end, with air in the middle of the series, the effects would take place as they do actually occur. Any body from the middle part of the series would point equatorially in the bodies above it and axially in those beneath it; for the matter which, like bismuth, goes from a strong to a weak point of action, may do so only because that substance, which is already at the place of weak action, tends to come to the place where the action is strong; just as in electrical induction the bodies best fitted to carry on the force are drawn into the shortest line of action. And so air in water, or even under mercury, is, or appears to be, drawn towards the magnetic pole.

2439. But if this were the true view, and air had such power amongst other bodies as to stand in the midst of them, then one would be led to expect that rarefaction of the air would affect its place, rendering it, perhaps, more diamagnetic, or at all events altering its situation in the list. If such were the case, bodies that set equatorially in it in one state of density, would, as it varied, change their position, and at last set axially: but this they do not do; and whether the rarefied air be compared with the magnetic or the diamagnetic class, or even with dense air, it keeps its place.

2440. Such a view also would make mere space magnetic, and precisely to the same degree as air and gases. Now though it may very well be, that space, air and gases, have the same general relation to magnetic force, it seems to me a great additional assumption to suppose that they are all absolutely magnetic, and in the midst of a series of bodies, rather than to suppose that they are in a normal or zero state. For the present, therefore, I incline to the former view, and consequently to the opinion that diamagnetics have a specific action antithetically distinct from ordinary magnetic action, and have thus presented us with a magnetic property new to our knowledge.

2441. The amount of this power in diamagnetic substances seems to be very small, when estimated by its dynamic effect, but the motion which it can generate is perhaps not the most striking measure of its force; and it is probable that when its nature is more intimately known to us, other effects produced by it and other indicators and measurers of its powers, than those so imperfectly made known in this paper, will come to our knowledge; and perhaps even new classes of phenomena will serve

to make it manifest and indicate its operation. It is very striking to observe the feeble condition of a helix when alone, and the astonishing force which, in giving and receiving, it manifests by association with a piece of soft iron. So also here we may hope for some analogous development of this element of power, so new as yet to our experience. It cannot for a moment be supposed, that, being given to natural bodies, it is either superfluous or insufficient, or unnecessary. It doubtless has its appointed office, and that, one which relates to the whole mass of the globe; and it is probably because of its relation to the whole earth, that its amount is necessarily so small (so to speak) in the portions of matter which we handle and subject to experiment. And small as it is, how vastly greater is this force, even in dynamic results, than the mighty power of gravitation, for instance, which binds the whole universe together, when manifested by masses of matter of equal magnitude!

2442. With a full conviction that the uses of this power in nature will be developed hereafter, and that they will prove, as all other natural results of force do, not merely important but essential, I will venture a few hasty observations.

2443. Matter cannot thus be affected by the magnetic forces without being itself concerned in the phenomenon, and exerting in turn a due amount of influence upon the magnetic force. It requires mere observation to be satisfied that when a magnet is acting upon a piece of soft iron, the iron itself, by the condition which its particles assume, carries on the force to distant points, giving it direction and concentration in a manner most striking. So also here the condition which the particles of intervening diamagnetics acquire, may be the very condition which carries on and causes the transfer of force through them. In former papers (1161, &c.)* I proposed a theory of electrical induction founded on the action of contiguous particles, with which I am now even more content than at the time of its proposition: and I then ventured to suggest that probably the lateral action of electrical currents which is equivalent to electrodynamic or *magnetic* action, was also conveyed onwards in a similar manner (1663. 1710. 1729. 1735.). At that time I could discover no peculiar condition of the intervening or diamagnetic matter; but now that we are able to distinguish such an action, so *like* in its nature in bodies so *unlike* in theirs, and by that so like in character to the manner in which the magnetic force pervades all kinds of bodies, being at the same time as universal in its presence as it is in its action; now that diamagnetics are shown not to be indifferent bodies, I feel still more confidence in repeating the same suggestion, and asking whether it may not be by the action of the contiguous or next succeeding particles that the magnetic force is carried onwards, and whether the peculiar condition acquired by diamagnetics when subject to magnetic action, is not that condition by which such propagation of the force is affected?

2444. Whichever view we take of solid and liquid substances, whether as forming two lists, or one great magnetic class (2424. 2437.), it will not, as far as I can perceive, affect the question. They are all subject to the influence of the magnetic lines of

* Philosophical Transactions, 1838, Part I.

force passing through them, and the virtual difference in property and character between any two substances taken from different places in the list (2424.) will be the same; for it is the differential relation of the two which governs their mutual effects.

2445. It is that group which includes air, gases, vapours, and even a vacuum which presents any difficulty to the mind; but here there is such a wonderful change in the physical constitution of the bodies, and such high powers in some respects are retained by them, whilst others seem to vanish, that we might almost expect some peculiar condition to be assumed in regard to a power so universal as the magnetic force. Electric induction being an action through distance, is varied enough amongst solid and liquid bodies; but, when it comes to be exerted in air or gases, where it most manifestly exists, it is alike in amount in all (1292.); neither does it vary in degree in air however rare or dense it may be (1284.). Now magnetic action may be considered as a mere function of electric force, and if it should be found to correspond with the latter in this particular relation to air, gases, &c., it would not excite in my mind any surprise.

2446. In reference to the manner in which it is possible for electric force, either static or dynamic, to be transferred from particle to particle when they are at a distance from each other, or across a vacuum, I have nothing to add to what I have said before (1614, &c.). The supposition that such can take place, can present nothing startling to the mind of those who have endeavoured to comprehend the radiation and the conduction of heat under one principle of action.

2447. When we consider the magnetic condition of the earth as a whole, without reference to its possible relation to the sun, and reflect upon the enormous amount of diamagnetic matters which, to our knowledge, forms its crust; and when we remember that magnetic curves of a certain amount of force and universal in their presence, are passing through these matters and keeping them constantly in that state of tension, and therefore of action, which I hope successfully to have developed, we cannot doubt but that some great purpose of utility to the system, and us its inhabitants, is thereby fulfilled, which now we shall have the pleasure of searching out.

2448. Of the substances which compose the crust of the earth, by far the greater portion belongs to the diamagnetic class; and though ferruginous and other magnetic matters, being more energetic in their action, are consequently more striking in their phenomena, we should be hasty in assuming that therefore they overrule entirely the effect of the former bodies. As regards the ocean, lakes, rivers, and the atmosphere, they will exert their peculiar effect almost uninfluenced by any magnetic matter in them; and as respects the rocks and mountains, their diamagnetic influence is perhaps greater than might be anticipated. I mentioned that, by adjusting water and a salt of iron together, I obtained a solution inactive in air (2422.); that is, by a due association of the forces of a body from each class, water and a salt of iron, the magnetic force of the latter was entirely counteracted by the diamagnetic force of the

former, and the mixture was neither attracted nor repelled. To produce this effect, it required that more than 48·6 grains of crystallized protosulphate of iron should be added to ten cubic inches of water (for these proportions gave a solution which still set equatorially), a quantity so large, that I was greatly astonished on observing the power of the water to overcome it. It is not therefore at all unlikely that many of the masses which form the crust of this our globe may have an excess of diamagnetic power and act accordingly.

2449. Though the general disposition of the magnetic curves which permeate and surround our globe resemble those of a very short magnet, and therefore give lines of force rapidly diverging in their general form, yet the magnitude of the system prevents us from observing any diminution of their power within small limits; so that probably any attempt on the surface of the earth to observe the tendency of matter to pass from stronger to weaker places of action would fail. Theoretically, however, and at first sight, I think a pound of bismuth or of water, estimated at the equator, where the magnetic needle does not dip, ought to weigh less when taken into latitudes where the dip is considerable; whilst a pound of iron, nickel, or cobalt, ought, under the same change of circumstances, to weigh more. If such should really prove to be the case, then a ball of iron and another of bismuth, attached to the ends of a delicate balance beam, should cause that beam to take different inclinations on different parts of the surface of the earth; and it does not seem quite impossible that an instrument to measure one of the conditions of terrestrial magnetic force might be constructed on such a principle.

2450. If one might speculate upon the effect of the whole system of curves upon very large masses, and these masses were in plates or rings, then they would, according to analogy with the magnetic field, place themselves equatorially. If Saturn were a magnet as the earth is, and his ring composed of diamagnetic substances, the tendency of the magnetic forces would be to place it in the position which it actually has.

2451. It is a curious sight to see a piece of wood, or of beef, or an apple, or a bottle of water repelled by a magnet, or taking the leaf of a tree and hanging it up between the poles, to observe it take an equatorial position. Whether any similar effects occur in nature among the myriads of forms which, upon all parts of its surface, are surrounded by air, and are subject to the action of lines of magnetic force, is a question which can only be answered by future observation.

2452. Of the interior of the earth we know nothing, but there are many reasons for believing that it is of a high temperature. On this supposition I have recently remarked, that at a certain distance from the surface downwards, magnetic substances must be entirely destitute, either of the power of retaining magnetism, or becoming magnetic by induction from currents in the crust or otherwise*. This is evidently an error; that the iron, &c. can retain no magnetic condition of itself, is

* Philosophical Magazine, 1845, vol. xxvii. p. 3.

very probably true, but that the magnetic metals and all their compounds retain a certain degree of power to become magnetic by induction, whatever their temperature, has now been proved (2344, &c.). The deep magnetic contents of the earth, therefore, though they probably do not constitute of themselves a central magnet, are just in the condition to act as a very soft iron core to the currents around them, or other inducing actions, and very likely are highly important in this respect. What the effect of the diamagnetic part may be under the influence of such inductive forces, we are not prepared to state; but as far as I have been able to observe, such bodies have not their power diminished by heat (2397.).

2453. If the sun have anything to do with the magnetism of the globe, then it is probable that part of its effect is due to the action of the light that comes to us from it; and in that expectation the air seems most strikingly placed round our sphere, investing it with a transparent diamagnetic, which therefore is permeable to his rays, and at the same time moving with great velocity across them. Such conditions seem to suggest the possibility of magnetism being there generated; but I shall do better to refrain from giving expression to these vague thoughts (though they will press in upon the mind), and first submitting them to rigid investigation by experiment, if they prove worthy, then present them hereafter to the Royal Society.

Royal Institution,
Dec. 22, 1845.

Feb. 2, 1846.—I add the following notes and references to these Researches:—

BRUGMANS first observed the repulsion of bismuth by a magnet in 1778. *Antonii Brugmans Magnetismus seu de affinitatibus magneticis observationes magneticæ.* Lugd. Batav. 1778, § 41.

M. LE BAILLIF on the Repulsion of a Magnet by Bismuth and Antimony, Bulletin Universel, 1827, vol. vii. p. 371; vol. viii. pp. 87. 91. 94.

SAIGEY on the Magnetism of certain natural combinations of Iron, and on the mutual repulsions of Bodies in general. Ibid. 1828, vol. ix. pp. 89. 167. 239.

SEEBECK on the Magnetic Polarity of different Metals, Alloys and Oxides. Ibid. 1828, vol. ix. p. 175.